Dark Matter Session

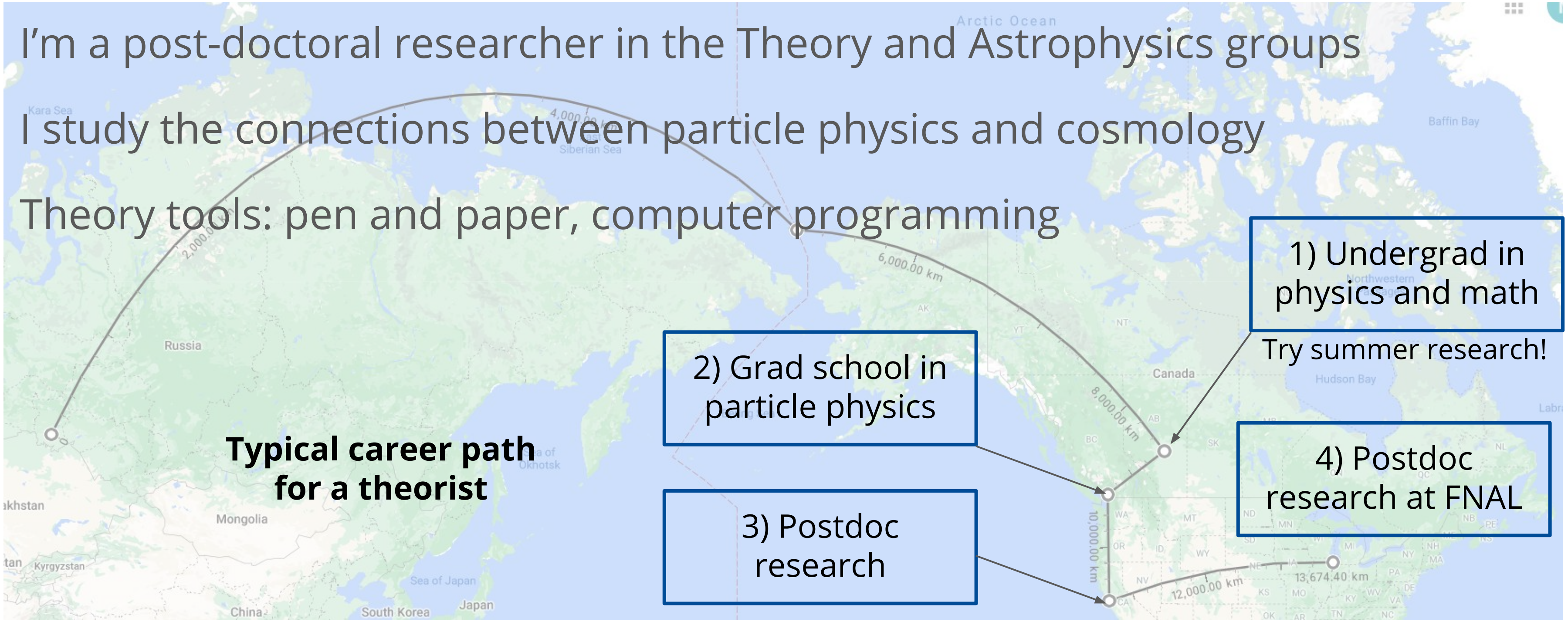
Nikita Blinov

Becoming a Theoretical Physicist

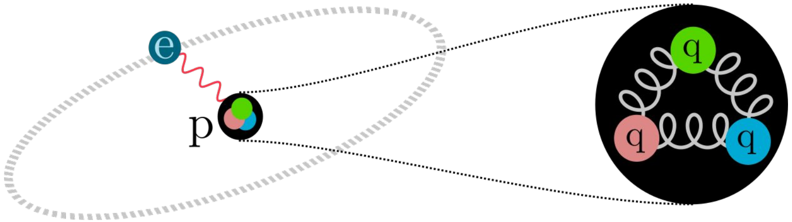
I'm a post-doctoral researcher in the Theory and Astrophysics groups

I study the connections between particle physics and cosmology

Theory tools: pen and paper, computer programming



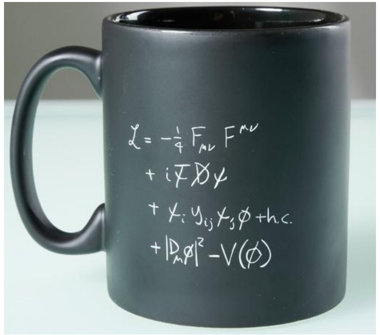
Why Particle Physics and Cosmology?



Atoms

Constituents of atoms

100 years of science!



CERN Gift Shop

We get to think about BIG questions like

- What are the fundamental ingredients of our universe?
- What was the early universe like?
- How do we use laboratory and astro observations to learn about these?

Missing Mass in the Universe?

What are the fundamental ingredients of our universe?

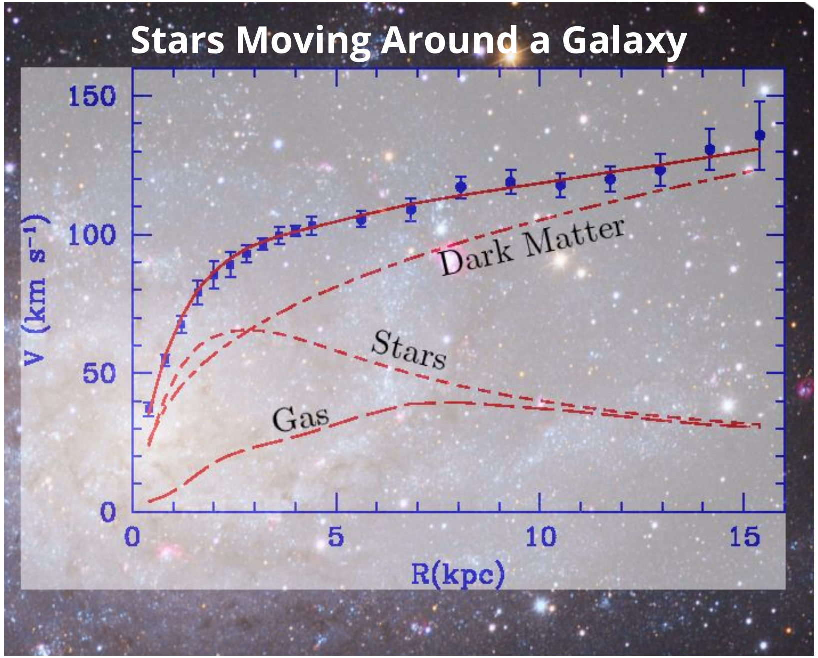
Universe Facts

Standard Model	
Photons	**0.005%**
Neutrinos	**0.004%**
Atoms	**5%**
Non-Standard Model	
Dark Energy	**68.5%**
Dark Matter	**26.5%**

*Abundances are based on the Standard Cosmological model. They may be different in other models.

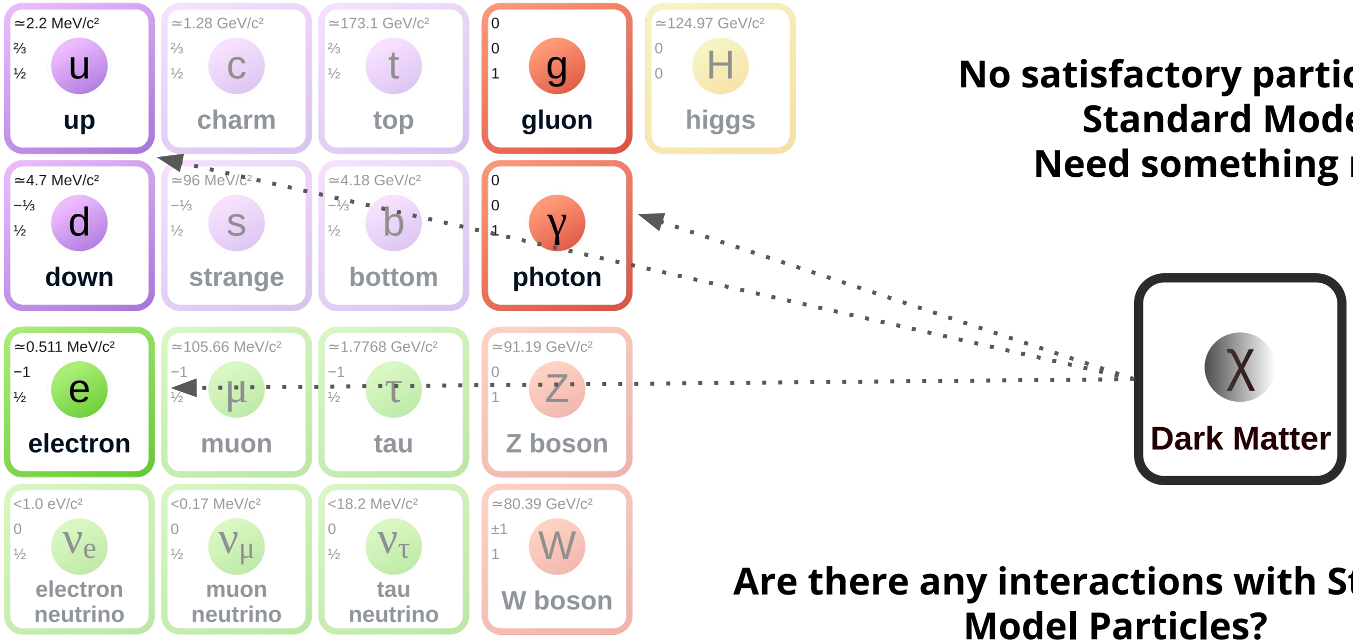
Familiar matter

???



Particle Physics vs Dark Matter

Standard Model of Elementary Particles



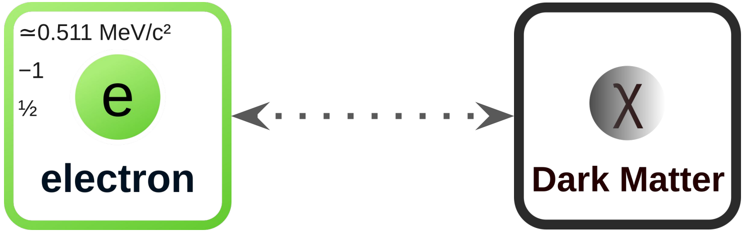
No satisfactory particle in the Standard Model: Need something new!

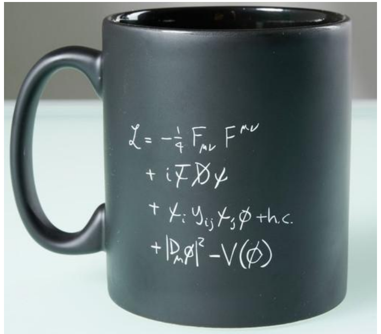
Are there any interactions with Standard Model Particles?

Wikipedia

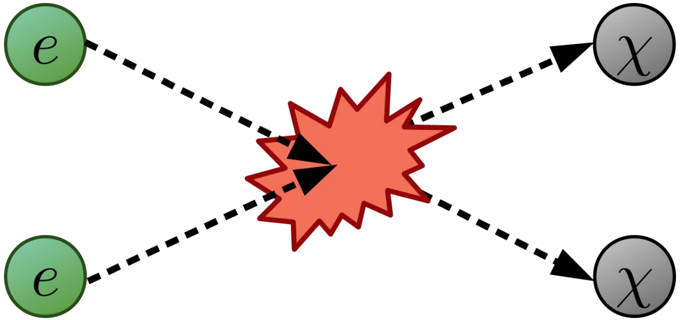
How Was Dark Matter Produced?

Need to make a hypothesis, for example





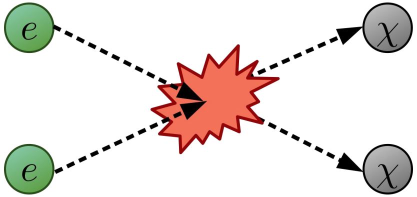
Lots of energetic electrons in the hot, dense soup of the early universe



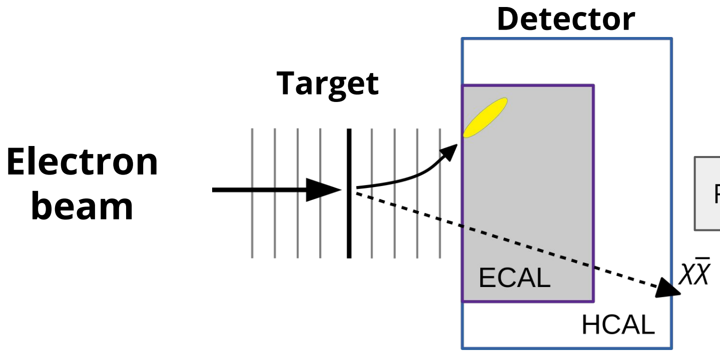
Dark Matter can be produced from collisions of familiar particles!

Searching for Dark Matter at Accelerators

Calculations of processes in the early universe inform us what experiments we need to test a given model

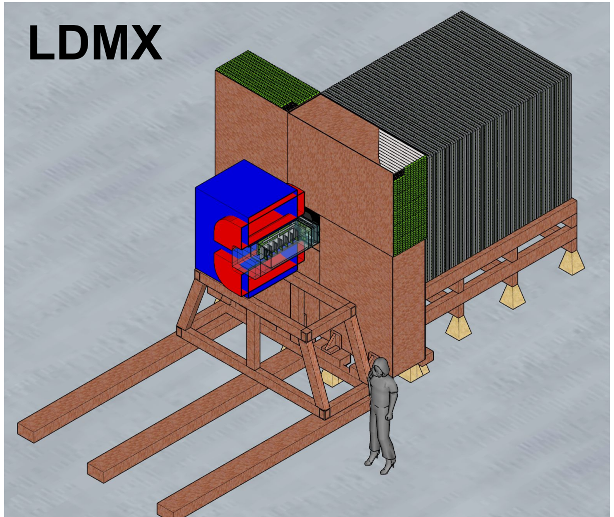


Same interactions as in early universe produce Dark Matter in beam-target collisions!



Theorist cartoon of an experiment

Realistic design by exp.

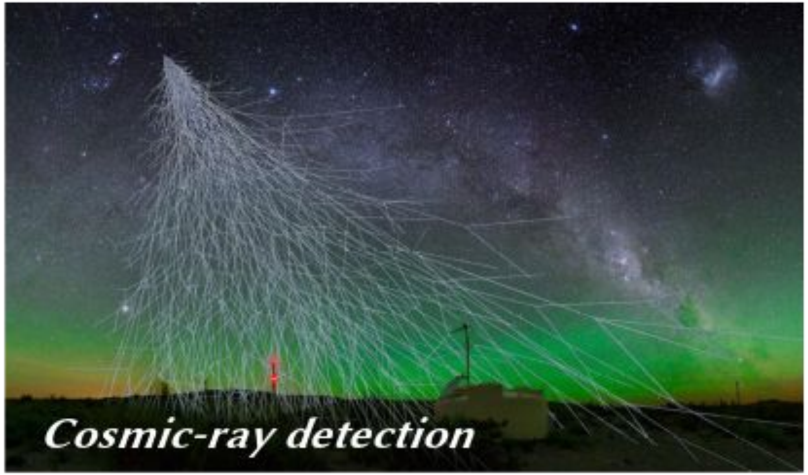


Ana Martina Botti

My background

- Physics diploma from Buenos Aires.
- Double doctoral degree in Astrophysics (Argentina/Germany).
- Post-doctoral researcher (transitioning from Buenos Aires to Fermilab).
- CPC Fellow soon.

A. Chantelauze, S. Staffi, L. Bret

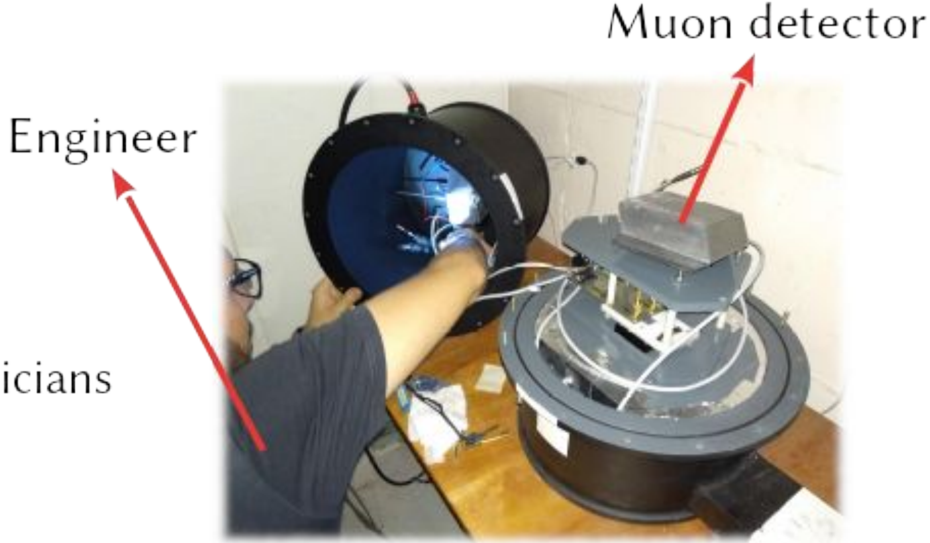


But also...

~ 7 years experience in industry (software development and IT security).
I use this experience **A LOT** in my everyday work!

Why experimental physics?

- Think, design and build experiments.
- Understand how "things" work (and why the don't!) and the Physics behind the technology.



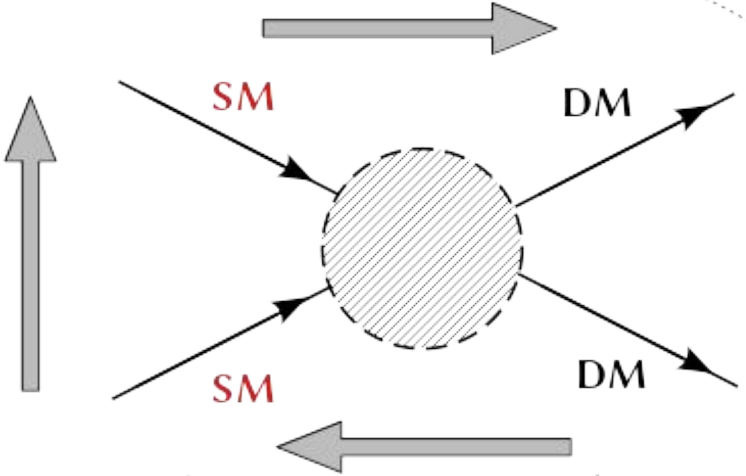
- Contribute to answer fundamental questions about nature.
- We work a lot with engineers and technicians (and we learn a lot from them too!).

Dark Matter detection

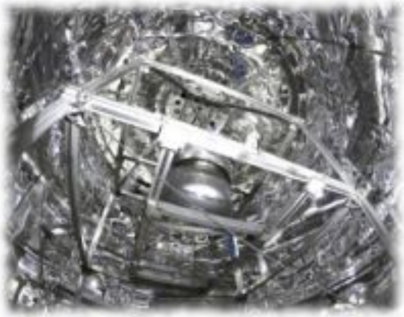
Colliders

Large Hadron Collider (LHC)
Credit: CERN

Direct detection
(this talk)



FermiLAT



Xenon 1T

Indirect detection
(Gammas, neutrinos and cosmic rays)

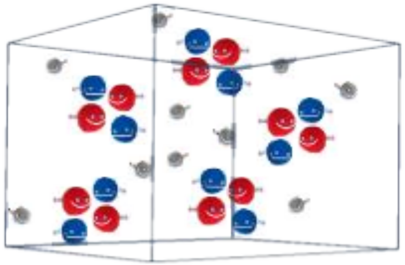
How do we build a detector for dark matter?

ParticleZoo.net

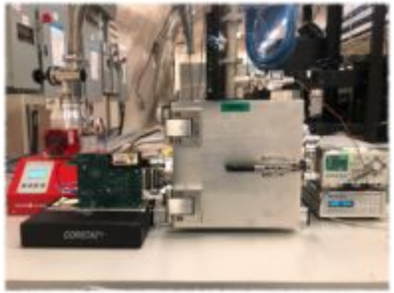
Some idea/s of what DM might be

ParticleZoo.net

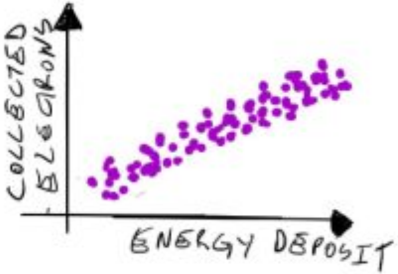
Some idea/s on how it interacts with known physics



Implement detection principle extending the available technology

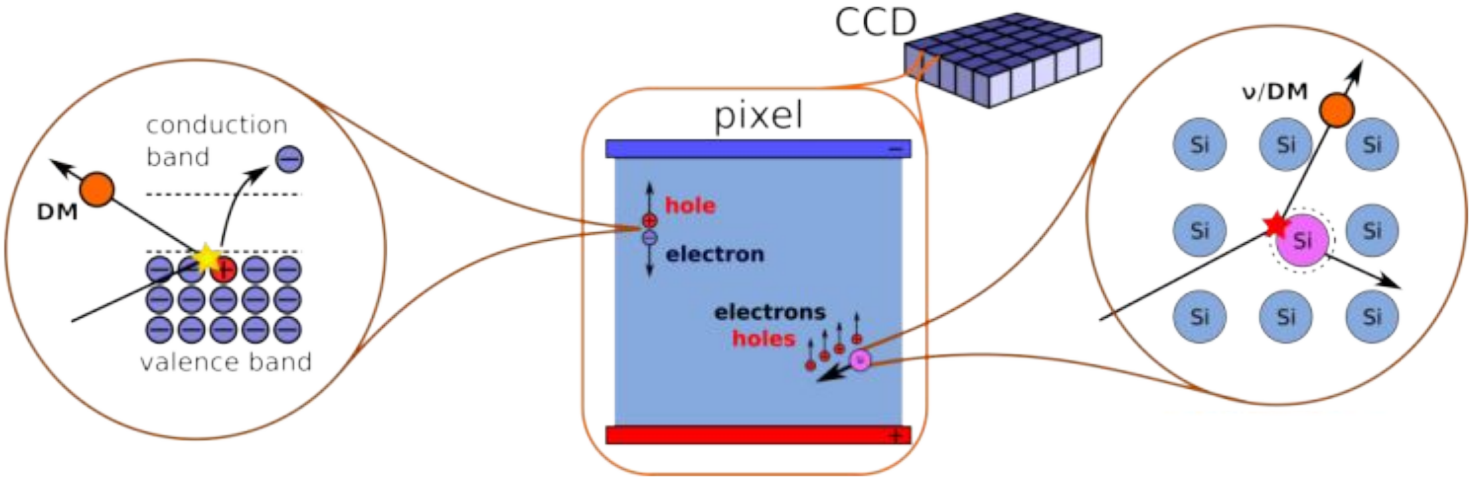


Mechanics + electronics + software



Understand the detector and go from signals to a plot

Dark Matter detection with silicon

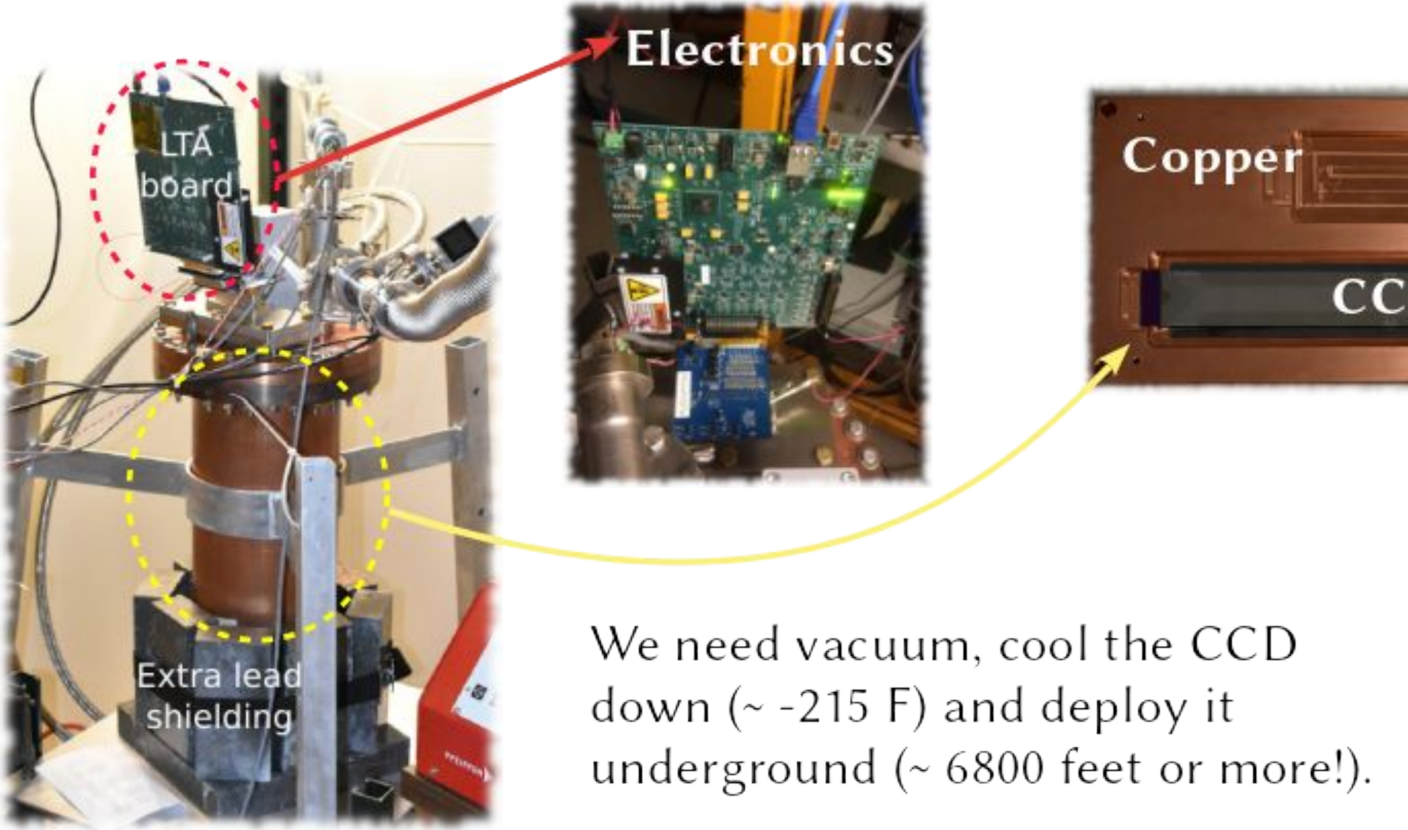


DM-electron interaction

DM-Nucleus interaction

We use science-grade CCDs (a very expensive digital camera!)

Dark Matter detection with silicon



We need vacuum, cool the CCD down (~ -215 F) and deploy it underground (~ 6800 feet or more!).

Foreseen detectors: SENSEI, DAMIC, OSCURA

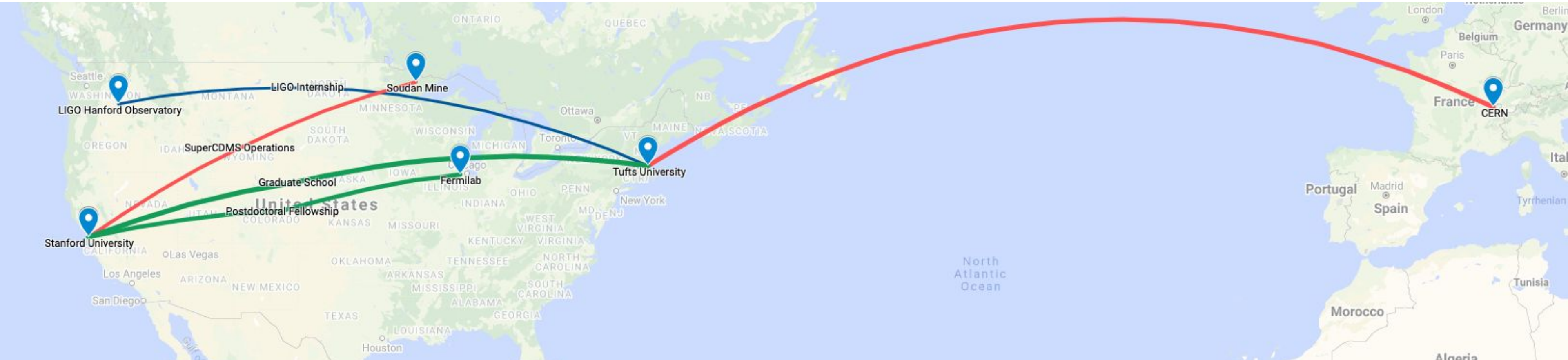
Noah Kurinsky

Becoming a Detector Physicist

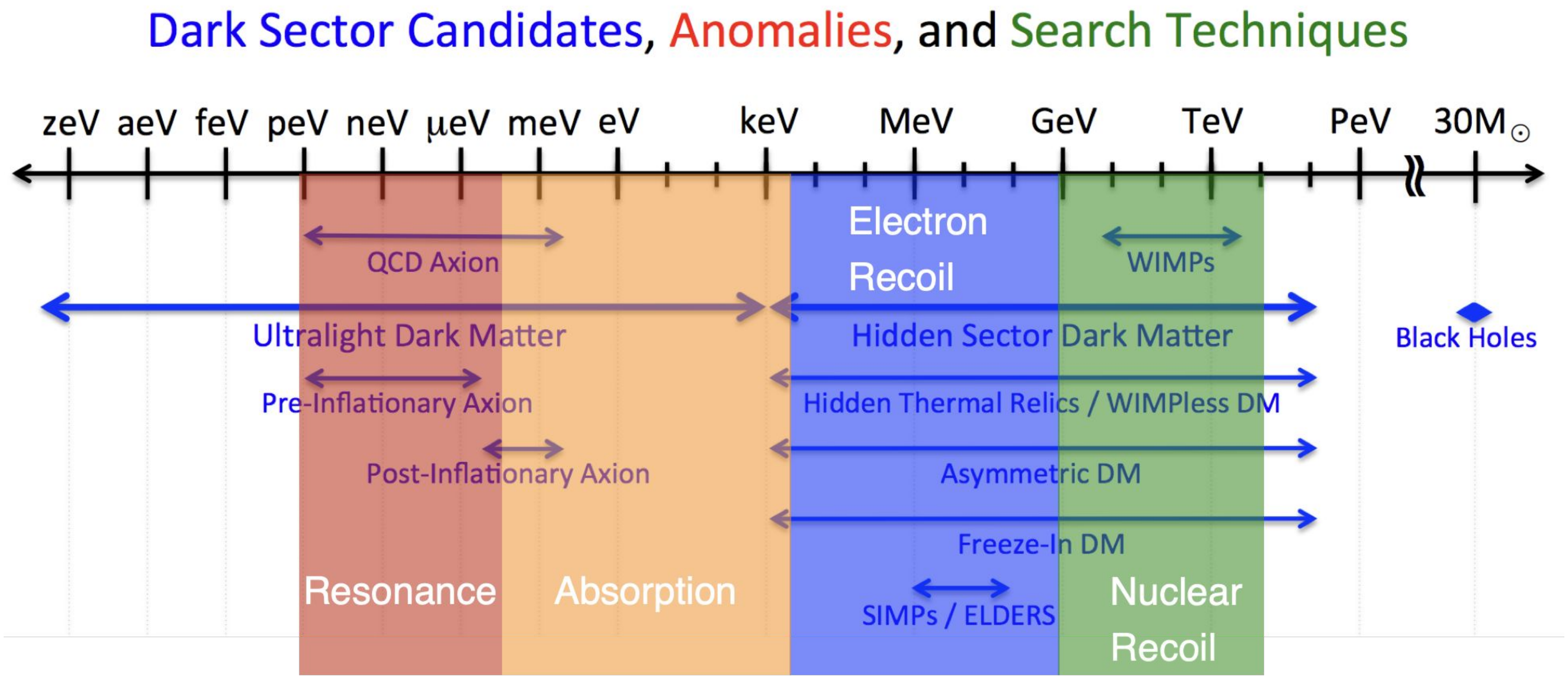
I'm a postdoctoral fellow in the Particle Physics Division, and part of the Cosmic Physics Center

I have undergrad degrees in Astrophysics & Engineering Physics

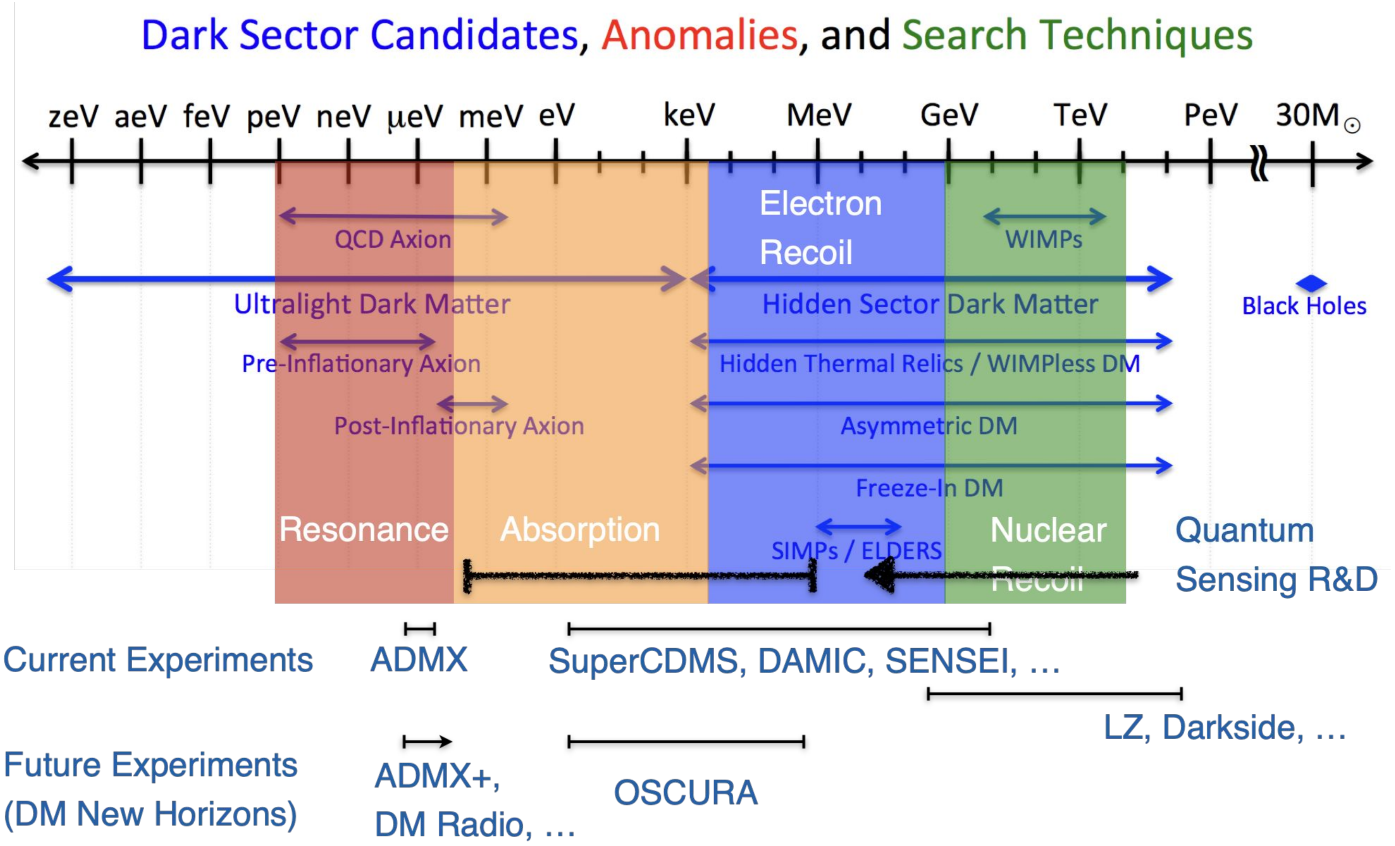
I got my PhD from Stanford designing detectors for Dark Matter searches



Types of DM Search Techniques



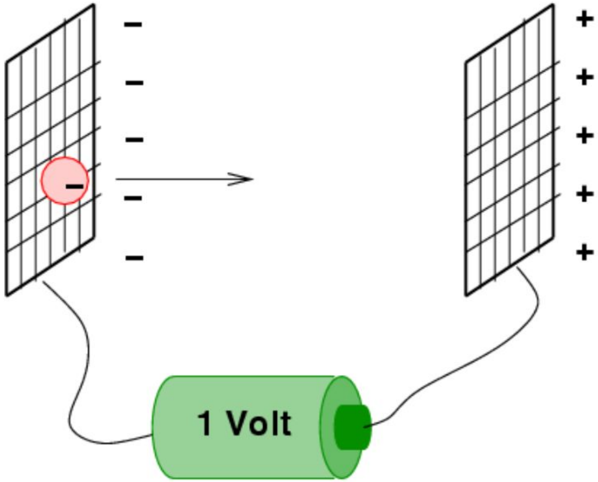
There are Many Experiments, Even Just at Fermilab!



Detecting Small Energy Deposits

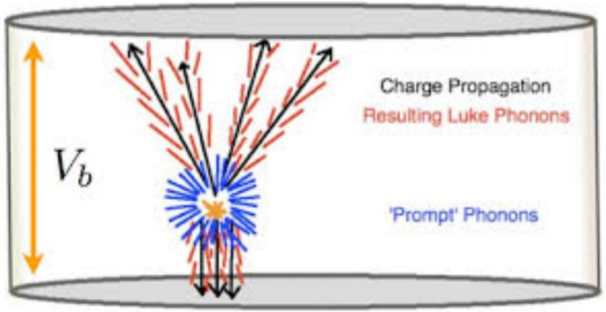
- The electron volt is a useful unit of energy for particles with a mass similar to the electron. It is defined as the energy gained by the electron when it passes across one volt of potential, roughly equal to the energy it would gain when going from the negative to positive terminals of a AA battery.

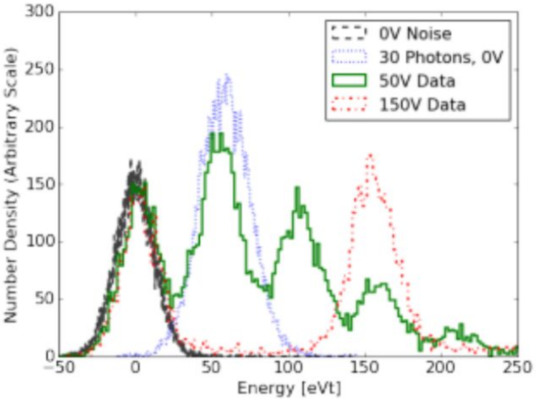
- To understand just how small this is, we can compare to units you may encounter in everyday life:
  - A conventional LED lightbulb uses around 5W of energy, which is 3e19 eV (30 million trillion)
  - A grain of sand which falls from a height of 3 feet gains an energy of 1e9 eV (one billion)
  - The grain of sand falling a distance equal to the width of a hair is 100 eV
  - For the same grain of sand to gain 1 eV during the fall, it would only need to move 1nm; roughly the size of 10 hydrogen atoms lined up!



Heat Detectors

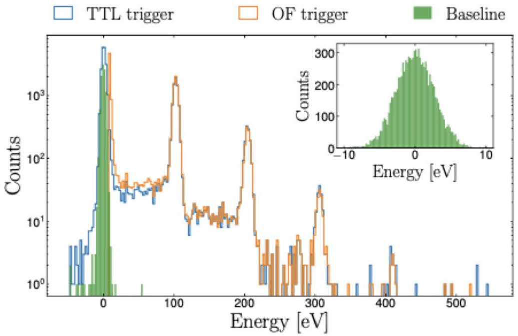
- In any recoil event, all energy is eventually converted to heat
- Heat is also produced when charges are drifted in an electric field; makes sense by energy conservation alone
- Total heat is initial recoil energy energy produced by drifting charge, as shown at right.
- Heat can be collected in sensitive ‘thermometers’ made with superconducting sensors!





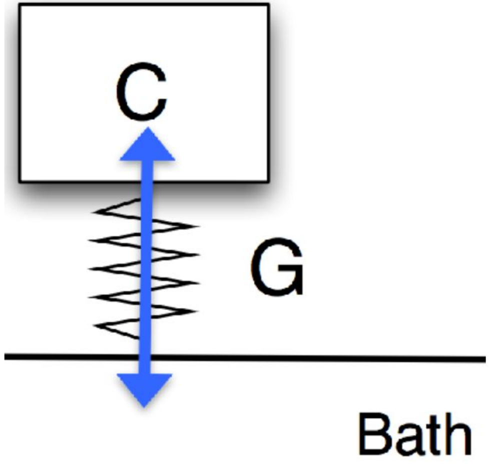
Romani et. al. 2017 (https://arxiv.org/abs/1710.09335)

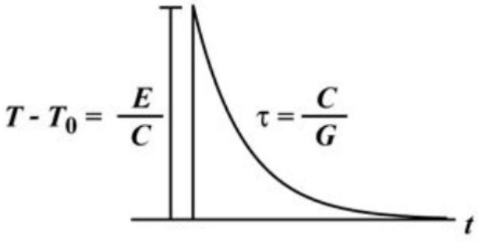
State of the Art:



Cryogenic Sensors

- Make your sensor very cold, so that a small energy deposit produces a large change in temperature
  - Most work at 10 mK, or -373C!
- Make your sensor very small, so that the heat capacity is small
  - Temperature change is E/C
- Provide a very cold heat sink to allow the detector to cool after a radiation event
  - Also helps understand the thermal response of the sensor
- A block of Tungsten at 50 mK has a heat capacity of 33 eV/K per cubic micron. How well you can measure temperature, and the size of the sensor, tells you how sensitive you are to injected energy.





NEXUS: Cryogenic Detector Test Facility

- 100m underground (right next to SENSEI)
- Base temperature of 10 mK
- Internal and external lead shielding
- Capable of running a wide variety of superconducting sensor technologies, including qubits